Status and plan for the dN/dx simulation and experiment

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CEPC Day

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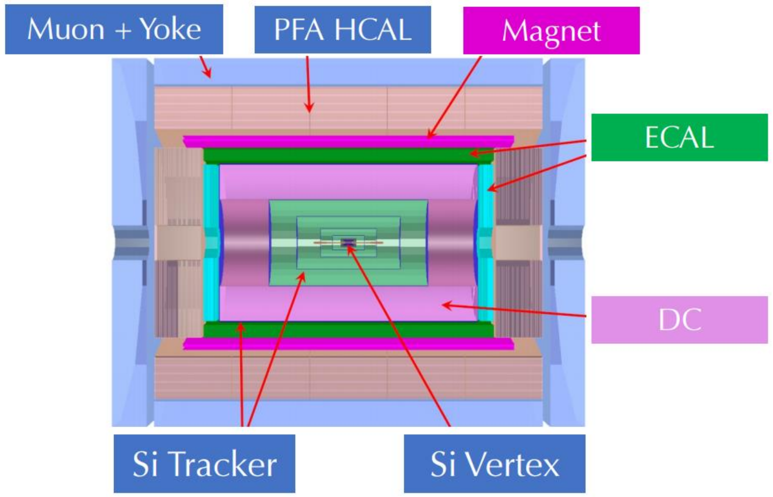
Outline

- Introduction
- Full simulation with the experiment
- Fast simulation
- Summary

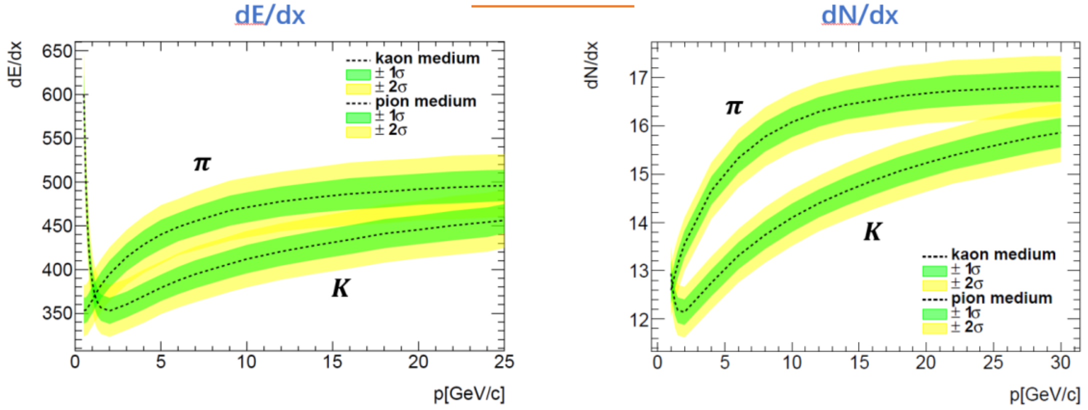
Introduction

- **Particle ID with a drift chamber is a key feature for the 4th conceptual detector**
- **Ionization measurement using the cluster counting technique (dN/dx) can benefit from small fluctuations**
- **Need detailed simulation for the feasibility and performance study**
- **Input from experiment tests is important for simulation**

4th Conceptual Detector



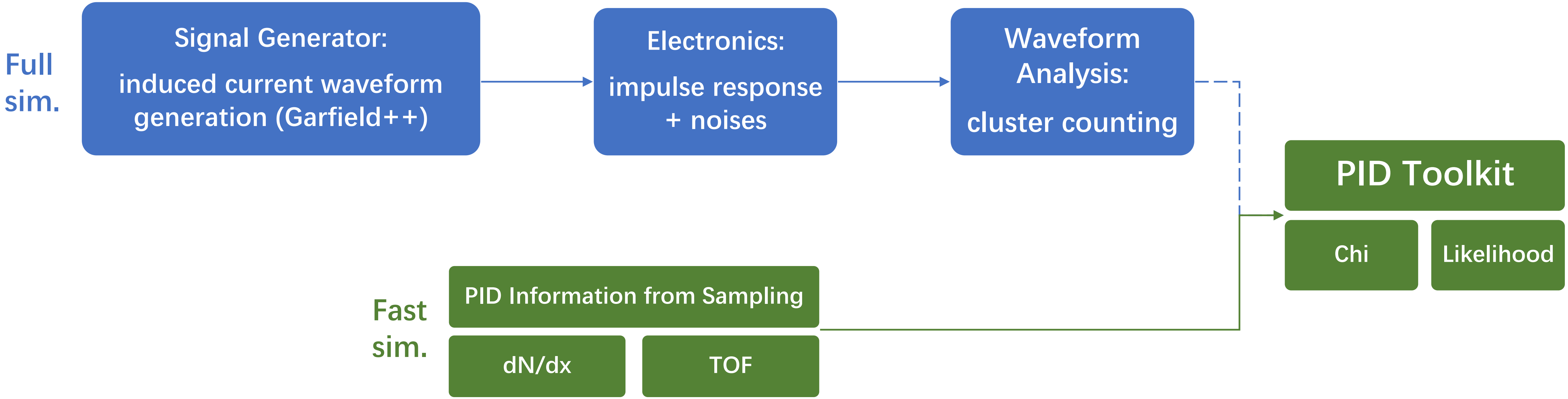
MC truth



Previous talks:

- Simulation framework and PID performances in April at Yangzhou workshop
- Noise generation in June at detector meeting

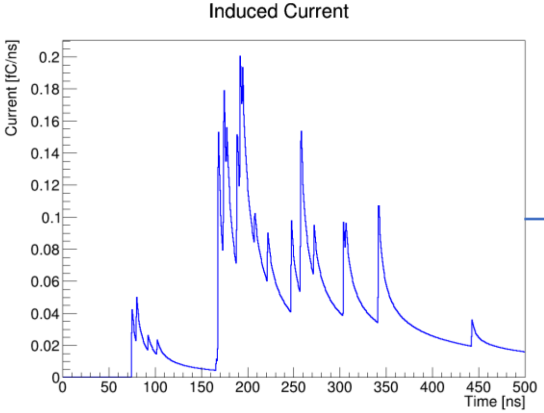
The simulation workflow

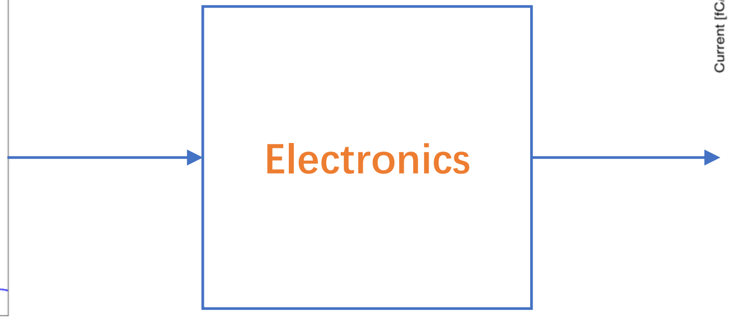


- A framework of dN/dx simulation is ready

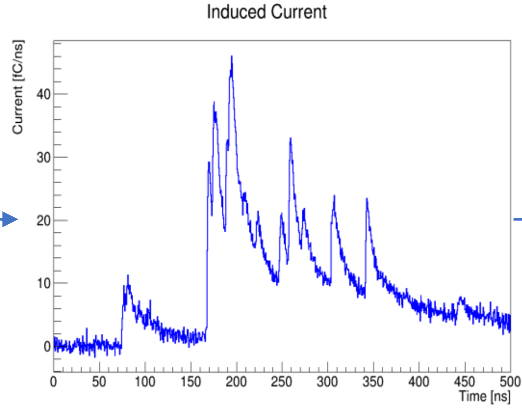
Full simulation

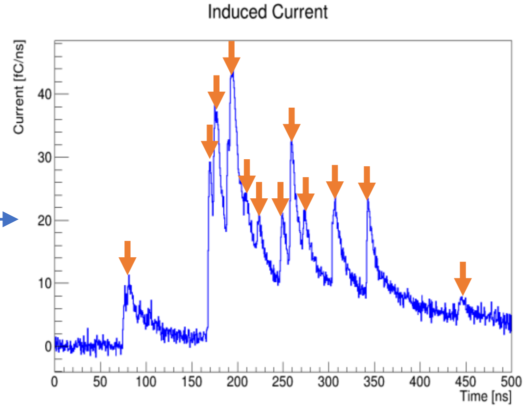
Induced current





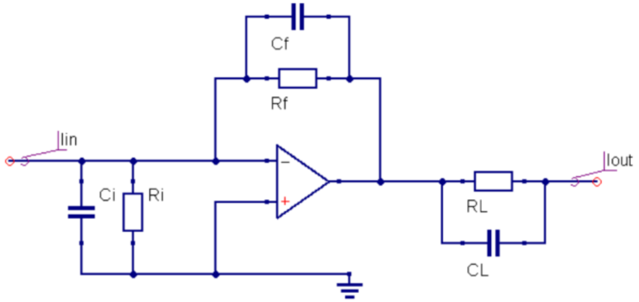
Realistic waveform





Signal generator (Garfield++):
- Heed: ionization process
- Magboltz: gas properties (drift/diffusion)

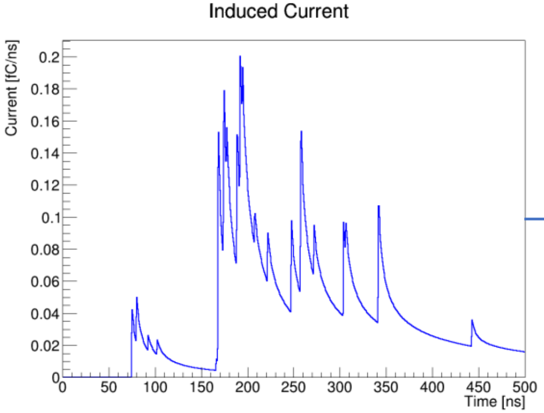
Electronics:
- Preamplifier
- Noises
- ADC



Counting method:
- Low pass smoothing (noise reducing):
  - $\mathbf{MA[i]} = \frac{1}{M} \times \sum_{k=0}^{K<M} S[i-k]$
- First derivative (peak finding):
  - D1[i] = MA[i] – MA[i – 1]

Full simulation

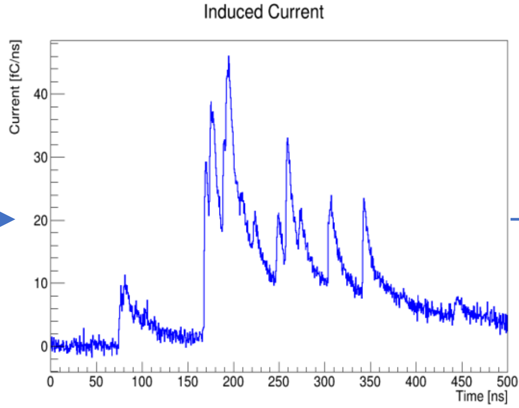
Induced current

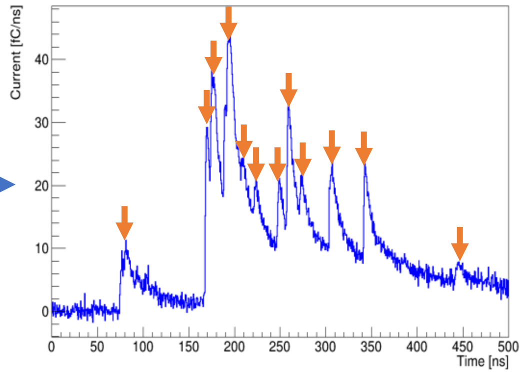


Need input form experiment

Electronics

Realistic waveform





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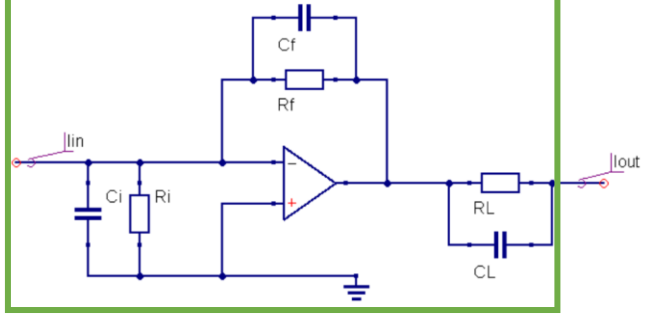

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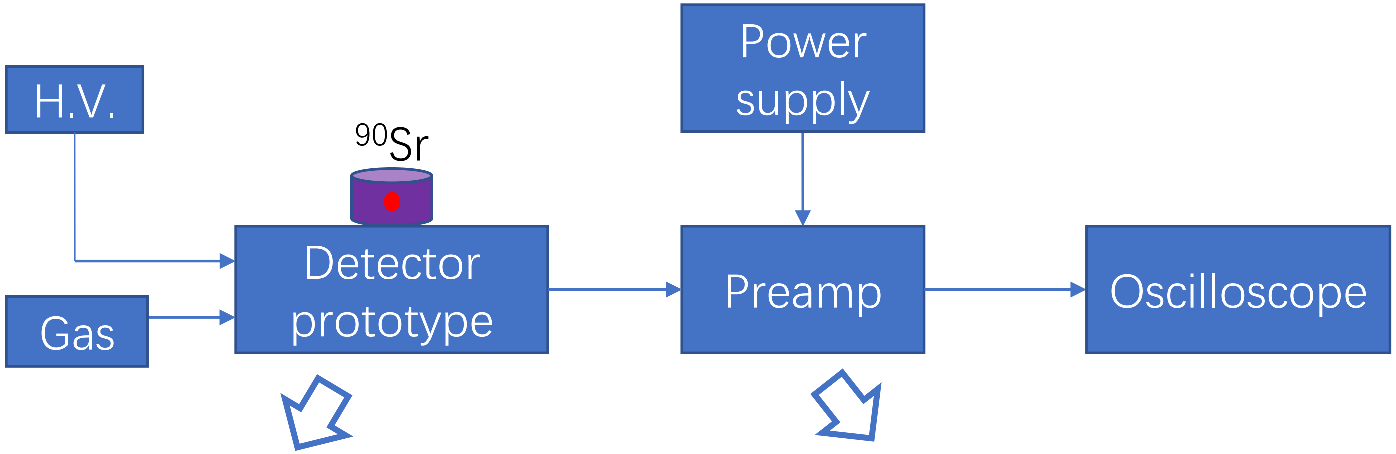
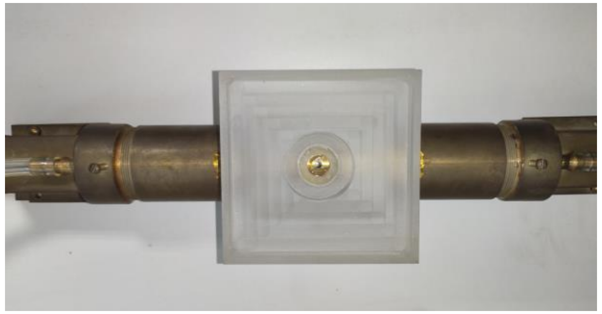
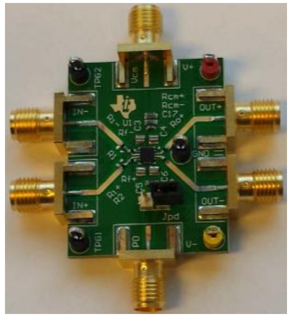
- Need experiment to provide more realistic electronics information
  - Noises
  - Preamplifier response

Experiment with a ^{90}Sr source + prototype detector





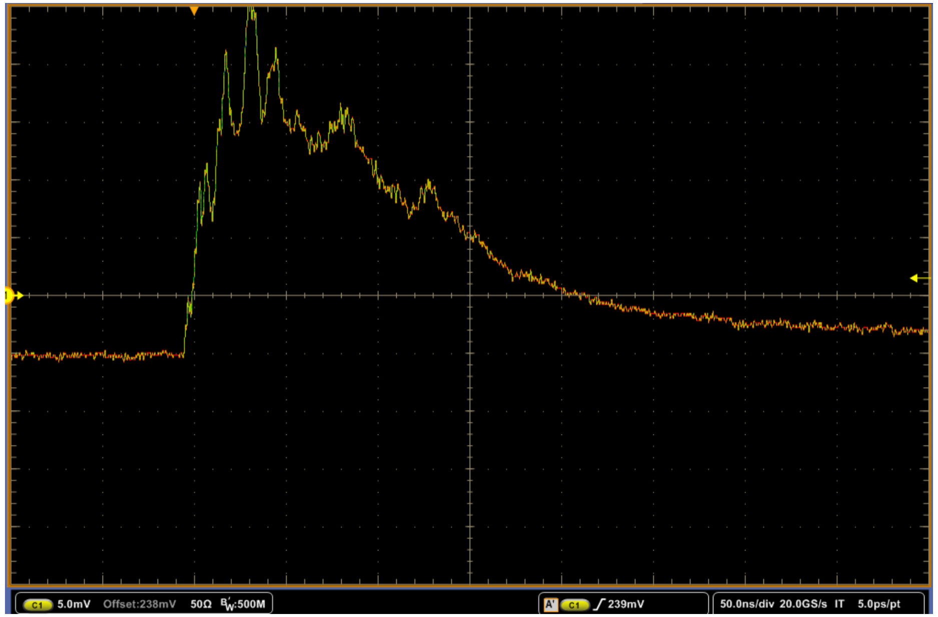


- ✓ **New amplifier: LMH5401 evaluation module**
- ✓ Gain bandwidth product (GBP): 8 GHz
- ✓ Gain : 12 dB (4 V-V)
- ✓ R_f: 127 Ω

- ✓ Proportional tube (φ32mm)
- ✓ Gas: 80% He + 20% iC_4H_{10}

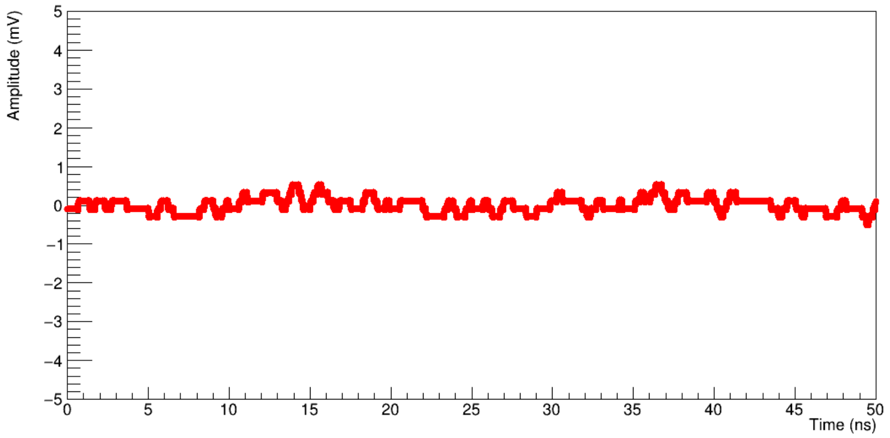
Waveform examples

- **Can observe peaks with fast rising edges in the waveforms**
- **Small-gain signal and low noise**
  - Signal amplitude: ~10^1 mV (max. peak)
  - Noise amplitude: ~10^{-1} mV (sigma)



Noise extraction

Extract noise information from the baseline of the waveform



FFT analysis of noises

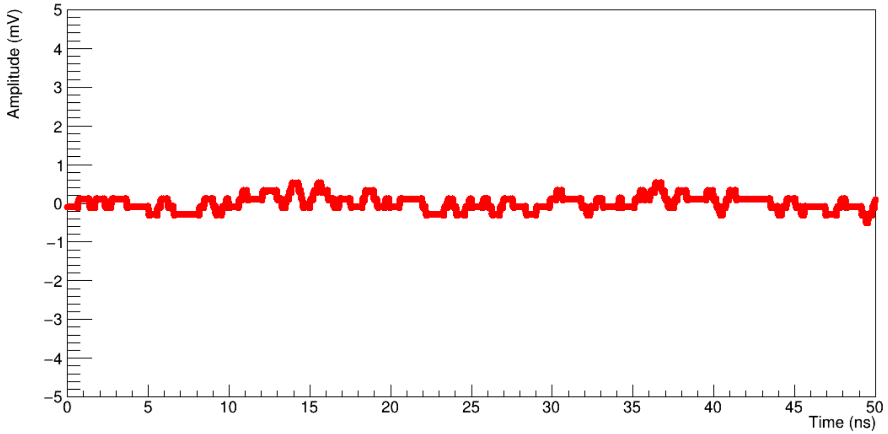
rectangular notation

$$x(t) = \sum_{k=0}^{+\infty} ReX[k]\cos(2\pi kt/T) - ImX[k]\sin(2\pi kt/T)$$

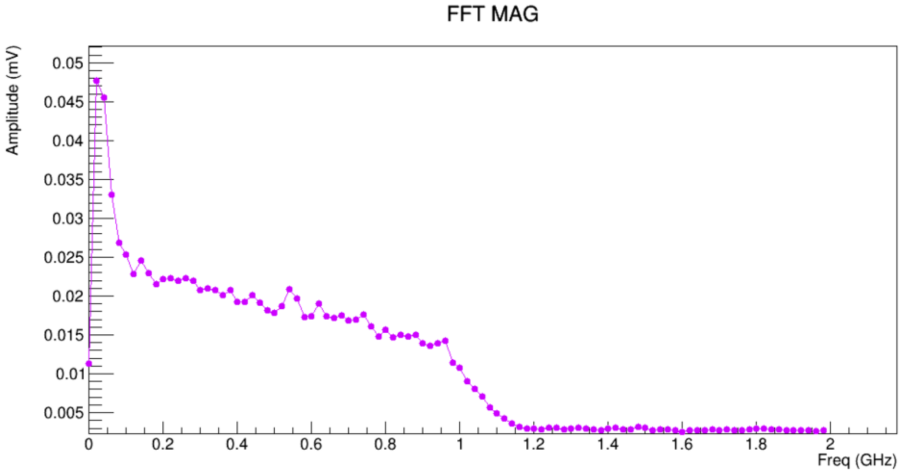
polar notation

$$MagX[k] = (ReX[k]^2 + ImX[k]^2)^{1/2}$$

$$PhaseX[k] = \arctan\left(\frac{ImX[k]}{ReX[k]}\right)$$



FFT

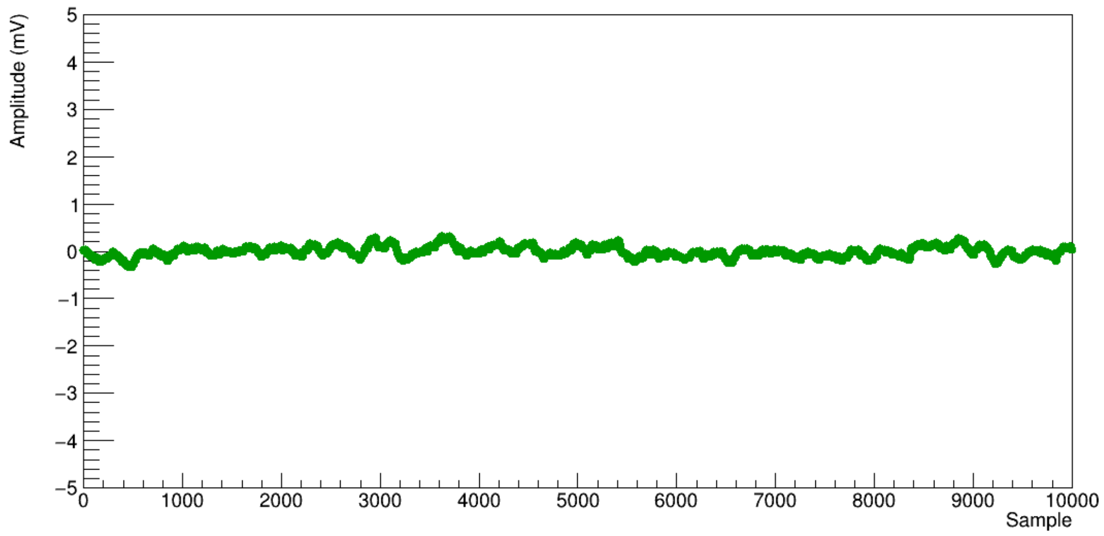


IFFT

- ✓ Average frequency spectra with 227 measurements
- ✓ Assume random phases

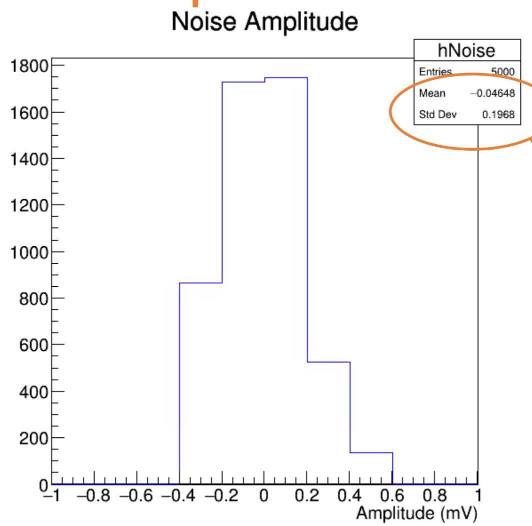
Noise generation

IFFT



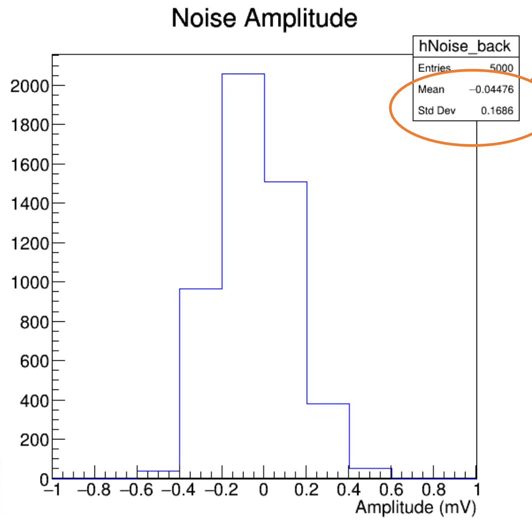
Noises are reproduced

Experiment



Similar distribution between experiment and simulation

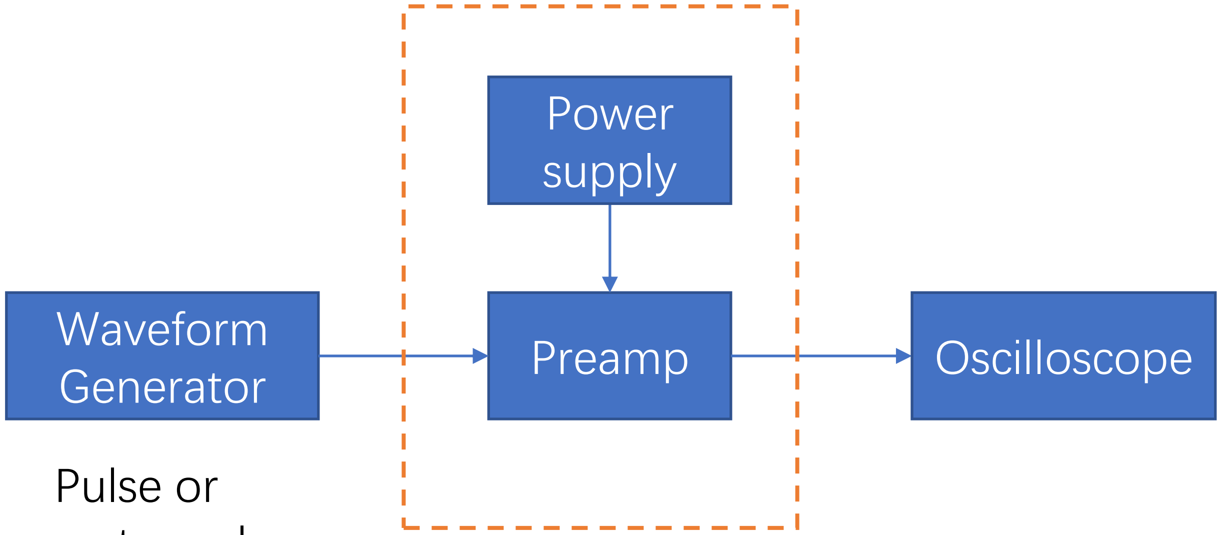
Simulation



(Bin size is limited by the measurement precision)

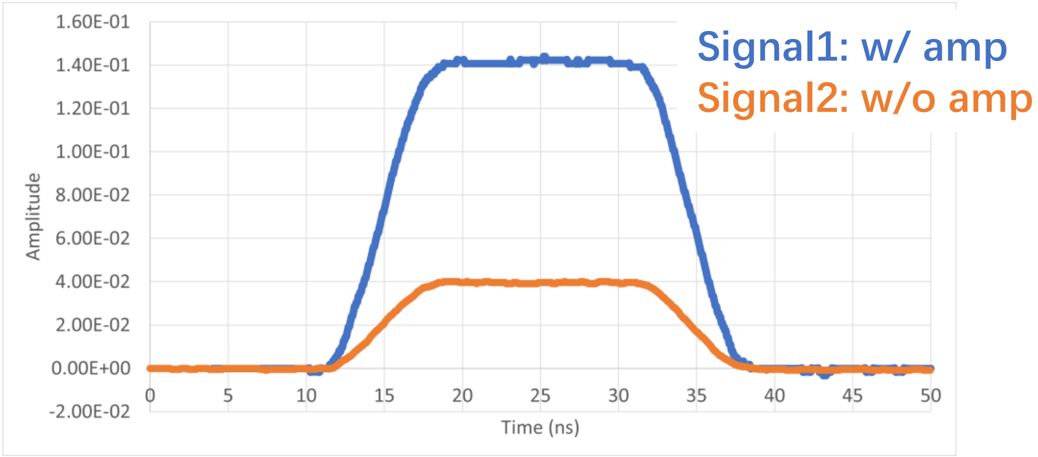
Experiment with a signal generator

With or without a preamplifier



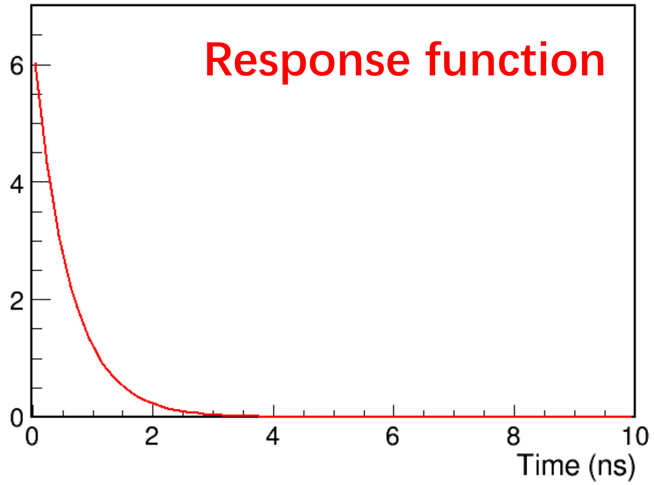
Pulse or rectangular waveform

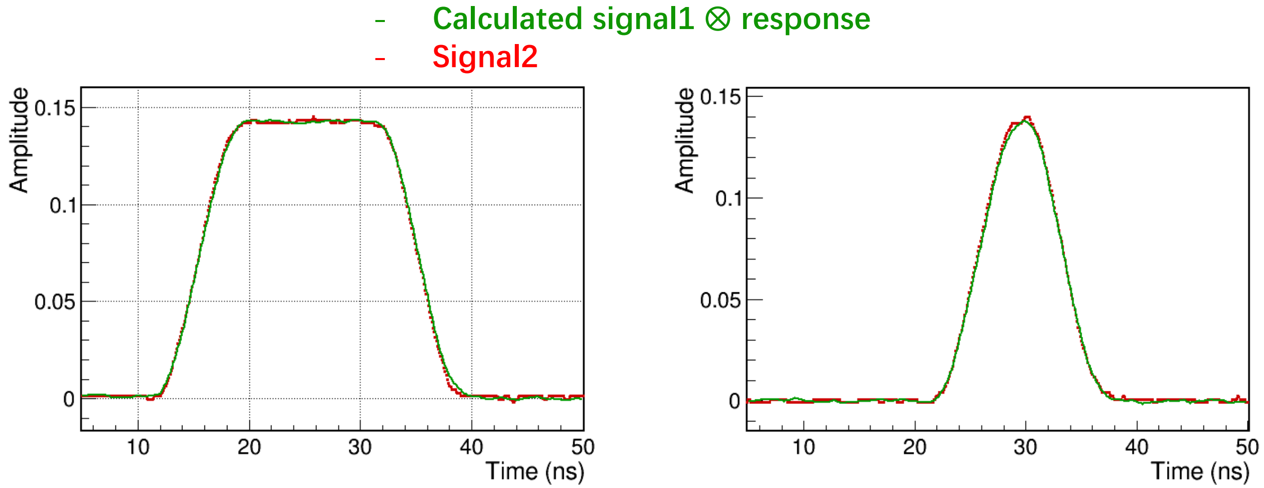
- Measure the signal with or without the pre-amplifier
- Try to extract the response of the pre-amplifier by analyzing the outputs



Response function analysis (preliminary)

$$\text{Signal1} \otimes \text{Response} = \text{Signal2}$$





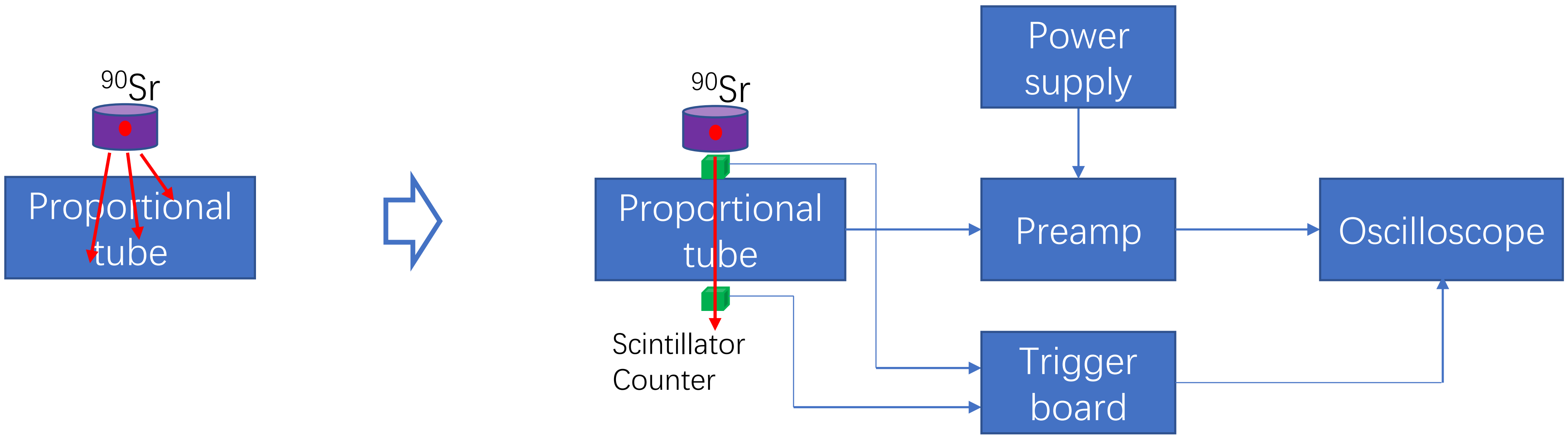
Extracted pre-amplifier response:

- Time constant ~0.6 ns (assume an exponential form)
- Risetime ~ 1ns: comparable with our previous simulation

Checks:

- Check the response function by convoluting to the signal w/o pre-amp.
- Show good consistency for different signal types

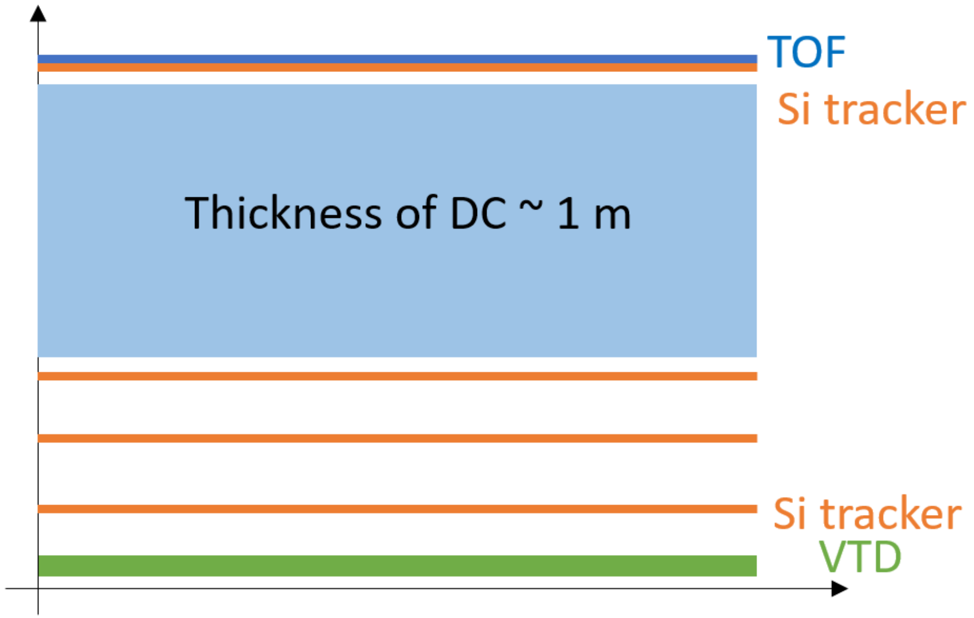
Plan: Prototype experiment with collimation



- **Constrain the entrance angle and track length of the emitted electrons from the Sr source**
  - Two scintillator counters with small active area will be used to provide trigger signals
- **Tune the gain of the preamplifier**

Fast simulation in CEPCSW

- **Main objective: Speeding up the simulation to enable the study of PID performance**
- **Method: Sampling dN/dx (truth) by a certain track length using Garfield.**
- **Geometry setup:**
  - Floating DC up to Rout =1.8m (1cm*100 layers)
  - A TOF detector surrounded at R = 1.8m

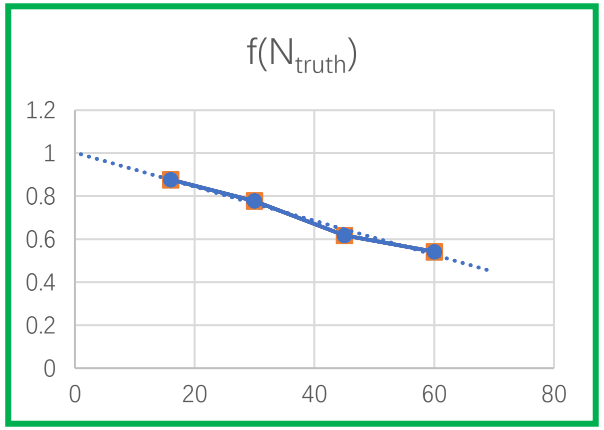


Geometry setup

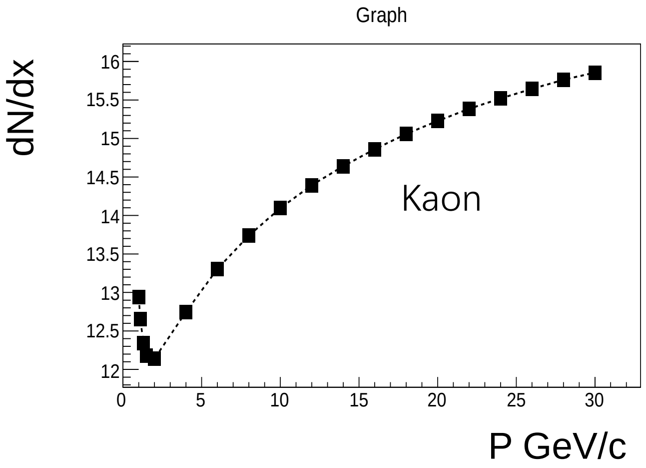
Fast simulation in CEPCSW (II)

- **dN/dx model:** $N = N_{truth} \times \epsilon = N_{truth} \times Gaus(f(N_{truth}), \sigma)$.
  - N_{truth}: Garfield sampling
  - ϵ: counting efficiency, tuned based on full simulation
- **TOF model:**
  - Assuming a resolution of 50 ps

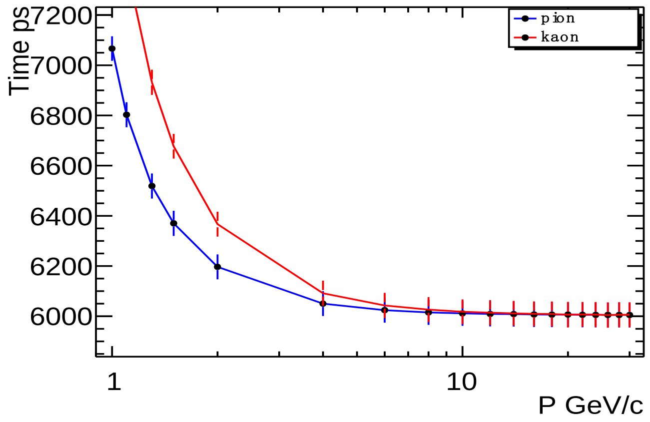
Tuned from full simulation



dN/dx model



TOF model

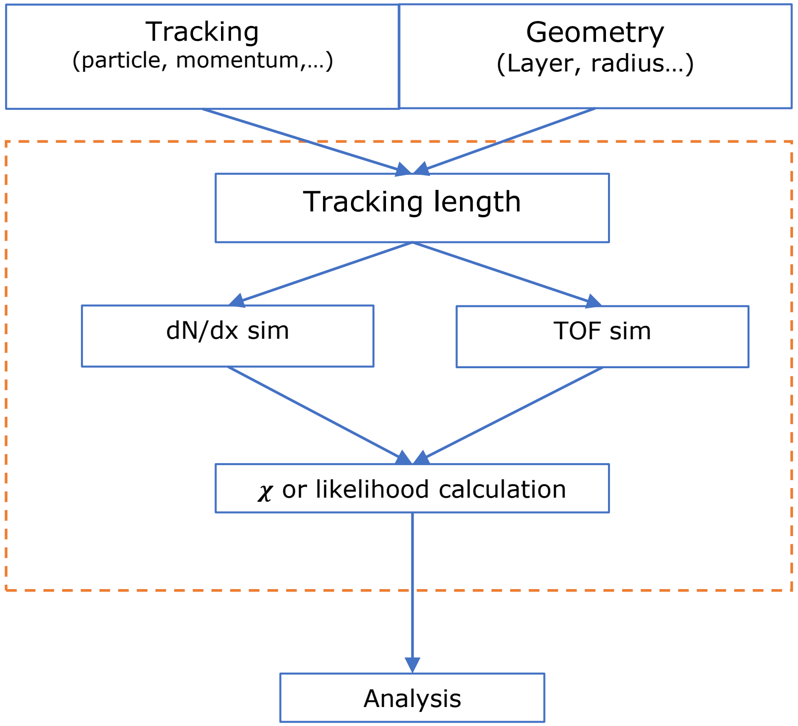


Fast simulation in CEPCSW (III)

- **Provide PID information:**
  - $\chi_t = \frac{t - t_{exp}}{\sigma_t}$, $\chi_{\frac{\mathrm{dN}}{\mathrm{dx}}} = \frac{dN/dx - dN/dx_{exp}}{\sigma_{\frac{dN}{dx}}}$
  - Likelihood: $\frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\chi_t^2} * \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\chi_{\frac{dN}{dx}}^2}$

- **A standalone package is also developed for physics analysis to do quick studies**
  - Input: basic track related parameter
    - angle, momentum, distance from initial point.
  - Output: the probability of assumption on each particle species, with dN/dx (and TOF, optional)
    - χ, likelihood

Structure of the fast simulation



Summary

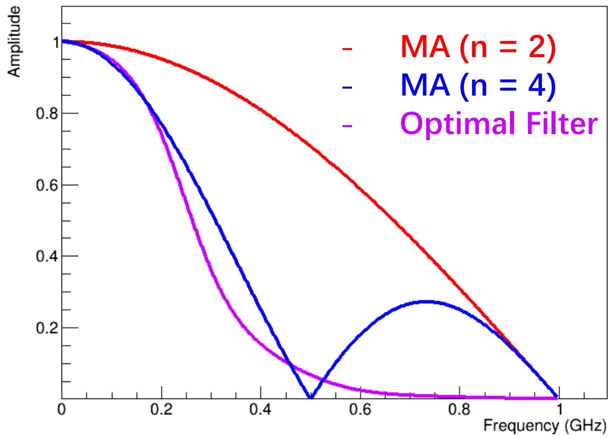
- **Initial prototype experiments are setup for the ionization measurement. The following information is extracted:**
  - Electronics noises
  - Response of the preamplifier (preliminary)

- **A fast simulation toolkit is developed for physics users to study the PID performance**
  - Parameters tuned based on full simulation
  - Provide χ^2 and likelihood for particle hypotheses

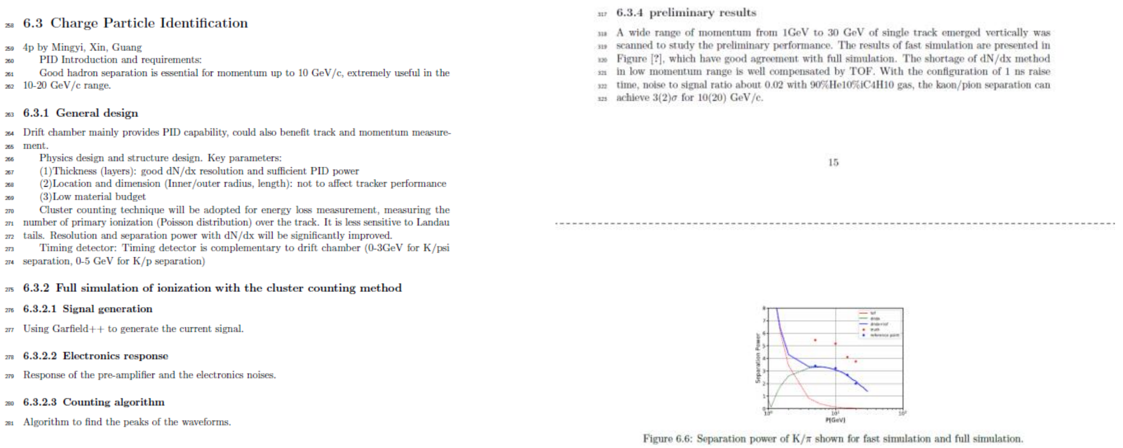
Outlook

- Improve the experiment in several aspects
- Import the results from the experiment to the full simulation
- Implement a low pass filter with better stopband attenuation
- Finish the 4th detector paper

Low-pass filter response



Paper draft



6.3 Charge Particle Identification

4p by Mingyi, Xin, Guang

PID Introduction and requirements:

Good hadron separation is essential for momentum up to 10 GeV/c, extremely useful in the 10-20 GeV/c range.

6.3.1 General design

Drift chamber mainly provides PID capability, could also benefit track and momentum measurement.

Physics design and structure design. Key parameters:

(1)Thickness (layers): good dN/dx resolution and sufficient PID power

(2)Location and dimension (Inner/outer radius, length): not to affect tracker performance

(3)Low material budget

Cluster counting technique will be adopted for energy loss measurement, measuring the number of primary ionization (Poisson distribution) over the track. It is less sensitive to Landau tails. Resolution and separation power with dN/dx will be significantly improved.

Timing detector: Timing detector is complementary to drift chamber (0-3GeV for K/psi separation, 0-5 GeV for K/p separation)

6.3.2 Full simulation of ionization with the cluster counting method

6.3.2.1 Signal generation

Using Garfield++ to generate the current signal.

6.3.2.2 Electronics response

Response of the pre-amplifier and the electronics noises.

6.3.2.3 Counting algorithm

Algorithm to find the peaks of the waveforms.

6.3.4 preliminary results

A wide range of momentum from 1GeV to 30 GeV of single track emerged vertically was scanned to study the preliminary performance. The results of fast simulation are presented in Figure [?], which have good agreement with full simulation. The shortage of dN/dx method in low momentum range is well compensated by TOF. With the configuration of 1 ns raise time, noise to signal ratio about 0.02 with 90%He10%iC4H10 gas, the kaon/pion separation can achieve 3(2)σ for 10(20) GeV/c.

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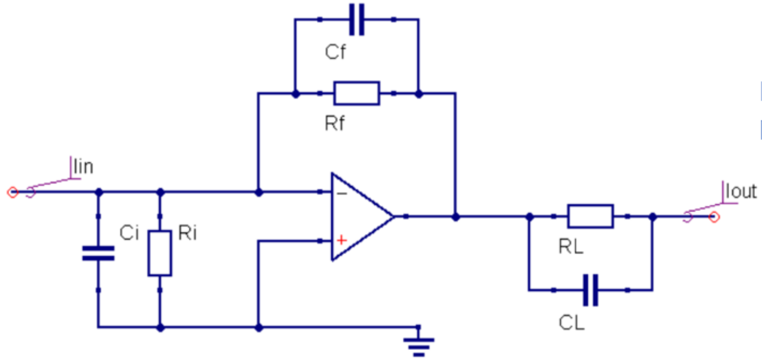
Figure 6.6: Separation power of K/π shown for fast simulation and full simulation.

Thank you for your attention!

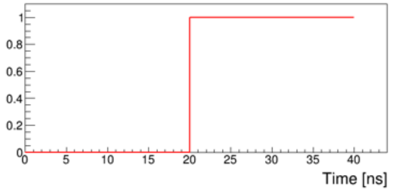
Backup

A simple current-sensitive preamplifier

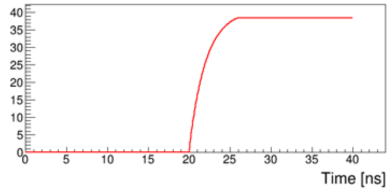


Time constants (τ) and risetime:

Step response:



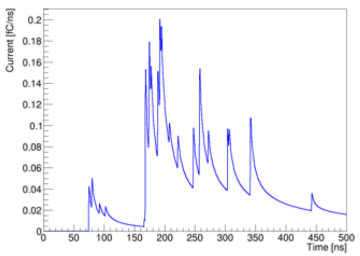
Response after preamplifier:



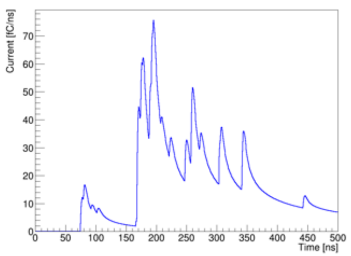
Time Constant (ns)	Risetime (ns)
0.5	0.95
1.0	1.85
2.0	3.70
3.0	5.50
4.0	7.35
5.0	9.20

Broaden of the waveforms with different time constants:

$\tau = 0\ ns$



$\tau = 2\ ns$



$\tau = 5\ ns$